THE PERMEABILITY

OF

CEMENT MORTAR,

BY

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THESIS

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PERMEABILITY OF CEMENT MORTARS.

Introductory.

The following report of tests on the permeability of cement and cement mortars is the record of a number of experiments made by the author in the spring of 1895. The experiments were made for a graduation thesis in the Department of Civil Engineering at the University of Illinois.

The words permeability and absorptive power are often confused. They are not synonomous, but have two distinct meanings. Absorptive power is the faculty which mortars exposed to the air, have of absorbing a certain quantity of liquid whenever immersed therein and left sufficiently long. "Permeability is the faculty whereby blocks of mortar submitted to the action of a head of water on one of their faces, transmits through their mass a certain quantity of water. Other things being equal the permeability would be measured by the amount of water which passes through the mortar in a given time."

A possible application of the results of tests on the permeability of mortars would be found in the construction of (1) reservoirs, cisterns, or in the construction wherever masonry is used to retain water; (2) sewers, especially brick sewers, where there are many cement joints; (3) tunnels where water is to be excluded; (4) dams; and (5) bridge piers and masonry under water.

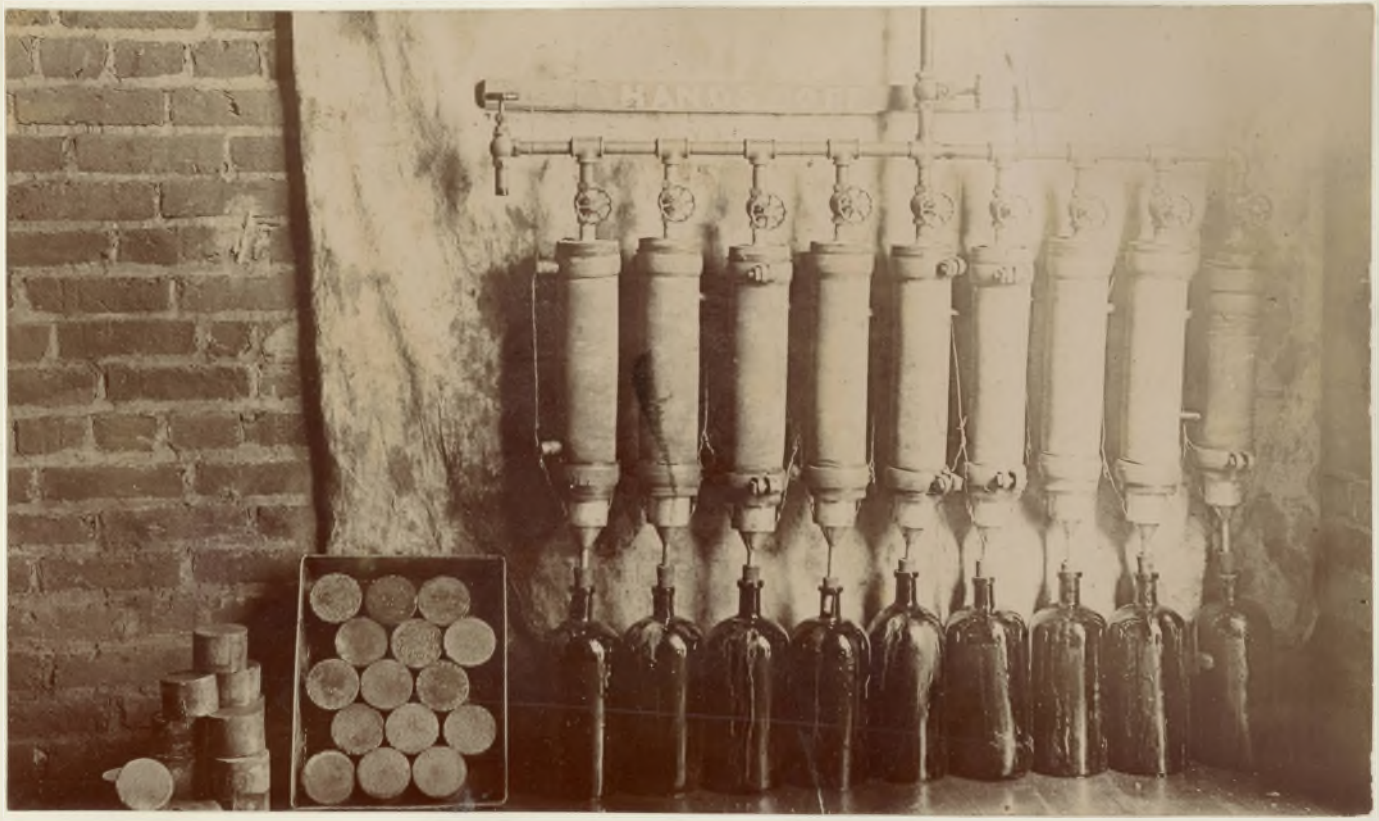
Literature of the Subject. But little has been published on the permeability of cement mortars. Some few experiments have been made, the results of which have been published in engineering periodicals; but in these experiments, almost without exception, sea water was used. In these cases, chemical action has taken place and the mortar has been more or less decomposed or disintegrated; and hence the results would not be applicable where fresh water was used. For accounts of experiments on the permeability of cement mortars see: Eng'g & Build. Rec., Nov.23, 1889; Jour. Frank. Inst., Mar., 1889; Eng'g News, Apr.6, 1889; and Pro. Inst. C. E., 1889.

Method of Making Tests.

Briefly the method of making the tests was as follows. Neat cement and cement mortar with various proportions of sand were moulded into three-inch cylinders. These cylinders were forced into the ends of short pieces of fire-hose which were connected with a head of water. The water passing through the mortar was caught in bottles and the amounts recorded.

The Apparatus.

In the top of the building in which the tests were made was placed a wash-tub. This held the water which produced the head under which the mortar, in the form of cylinders, were placed. This head amounted to 33.6 ± 0.3 ft., producing a pressure of 14.4 ± 0.13 lbs. per square inch on the mortar. Leading downward from the tub was a 1/2-inch pipe, at the lower end of which was placed a globe valve. By means of nipples, crosses, tees, and valves, the apparatus as shown in the photograph on the next

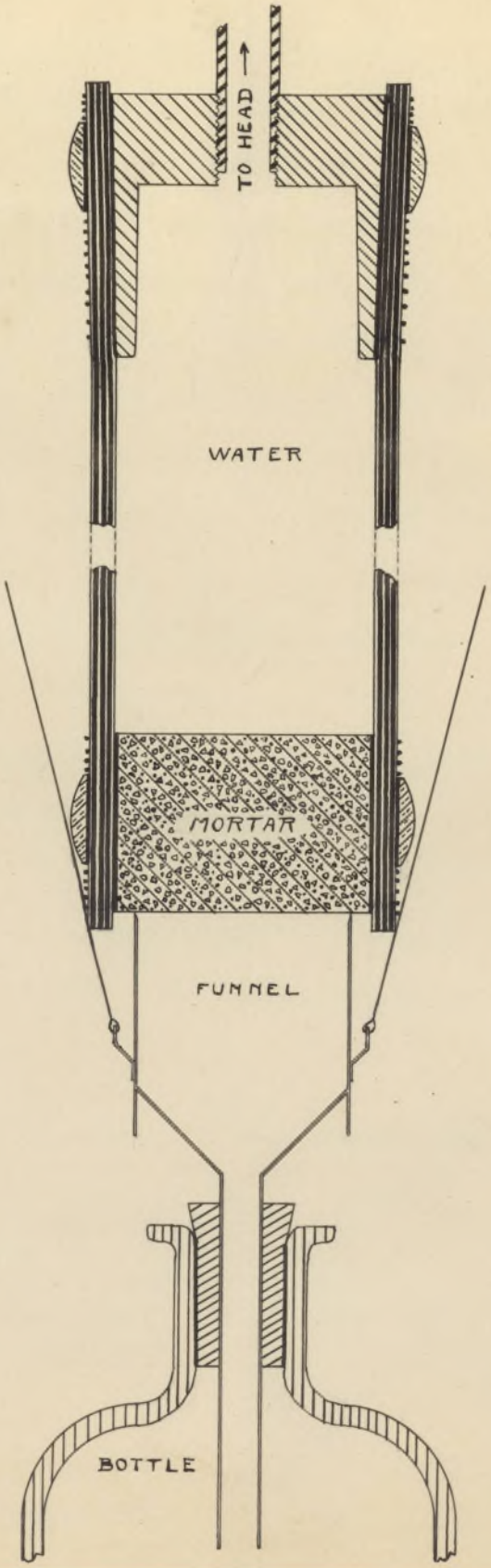


APPARATUS FOR TESTING
PERMEABILITY OF CEMENT MORTAR

page was constructed. With this construction nine outlets were obtained, at each end of which a nipple was fastened. On the end of each nipple was screwed a casting as shown in Plate I. This casting was fitted over a 3-inch two-ply hose, 15 inches long. To make the joint between the hose and casting water tight the hose over the casting was clamped with a hose-clamp and firmly wrapped with small iron wire. In the lower end of the hose was placed the mortar cylinder to be tested. A hose-clamp was fastened on the outside of the hose over the cylinder, care being taken, especially with the weaker mortars, to prevent their being crushed by clamping too tightly. In addition, the hose over the cylinder was tightly wired. In this manner a tight joint was secured between the hose and the mortar cylinder.

A tin funnel was firmly held against the bottom of the cylinder. The cross-section of the funnel is shown in Plate I. The diameter of the funnel is 2.52 inches. When the funnel is placed in the center of the cylinder of mortar, a space is left between the edge of the funnel and the edge of the cylinder of 0.24 inch. The top of the funnel is filed to a sharp edge, consequently a ~~sharp~~, firm bearing on the mortar cylinder is secured. Tin lugs are fastened to the sides of the funnel, through which wires are fastened to hold the funnel in place. All water which passes through the mortar not covered by the funnel will, owing to the projection of the side drop to the floor. The lower end of the funnel fits into a cork stopper which, in turn, fits into the neck of a 5-pint bottle, where

PLATE I



the water passing through the mortar is finally retained.

The Material.

The Cement. The cements used were German Portland, Louisville, and Utica. The German Portland and Louisville were the ordinary commercial cement and had been in the possession of the University for about one year. The German Portland is considered to be the best slow-setting cement made. The Louisville was the "Black Diamond" brand, manufactured in Louisville, Ky. This cement is quick-setting and, owing to its cheapness, is largely used on sewers, etc. The Utica cement, manufactured at Utica, Ill., is considered among the best of the so called quick-setting cements, although it is relatively a slow-setting cement. The Utica cement was obtained from the manufacturers with their knowledge of the use to which it was to be put.

The tensile strength of neat cement briquettes having a cross-section of one square inch is given in Table I. The briquettes were tested in a Riehlé testing machine with rubber tipped grips.

TABLE I.
Tensile Strength of Neat Cement Briquettes.

Ref. No.	Kind of Cement.		
	German Portland# 23 % water	Louisville* 34 % water	Utica# 36 % water
1	487 lbs. per sq. in.	174 lbs. per sq. in.	110 lbs. per sq. in.
2	555	155	92
3	434	180	96
4	457	155	95
5	550	180	75
6	531	170	90
Average	502	169	93

* Briquettes two days in air and nine in water.
\# " one day " " " six " "

The Sand. The sand was of two kinds; viz., (1) crushed quartz, and (2) Mississipi River sand. The crushed quartz, which was clean and sharp, passed a No. 20 sieve and was rejected by a No. 30. The river sand was clean and sharp, not however as sharp as the quartz. Four grades were used; viz., (1) that passing a No. 10 sieve and rejected by a No. 20; (2) all grades passing a No. 20 sieve; (3) that passing a No. 20 and rejected by a No. 30 sieve and (4) all grades passing a No. 30 sieve.

The Water. The water used, both in mixing the mortar and in testing permeability, was from the Champaign and Urbana Waterworks. This water is "hard", and comes from a bed of gravel about eighty feet below the surface.

Preparation of Specimen.

Moulding. The method of making the test specimen was as follows:

The proper proportion of cement and sand, weighed to the nearest gram, were thoroughly mixed dry, then put on a slate table and mixed with a trowel, water being added until the mortar showed signs of "flushing" when firmly rubbed with the trowel. The mortar was then put into a mould which consisted of a three-inch, cast-iron, pump cylinder firmly held to the table-top by means of iron clamps. The cement was then thoroughly rammed by hand with a hard-wood cylinder which just fitted into the pump cylinder. When neat cement was moulded, the pump cylinder was oiled to prevent the cement from sticking. The neat cement was allowed to thoroughly set in the mould before being removed,

as it would not hold its form if removed immediately after ramming. As no difficulty was experienced in this respect with the mixtures of sand and cement, they were removed from the mould before having set, i. e., in from two to ten minutes after being put into the mould.

The mortar, after being taken from the mould, was placed on glass in a pan, covered with a damp cloth, and left for a day, after which it was put in water and left until ready to test.

Painting Mortar Cylinder. When ready to test, the mortar cylinder was allowed to dry for an hour when it was painted with a coat of shellac. After the first coat had dried, a second was added and the cylinder immediately forced into the end of a three-inch hose. By the painting, a tight joint was made between the hose and the mortar, thus preventing a leakage of water, and what was of more importance all water which was caught in the bottles had to pass the entire length of the mortar cylinder, all short cuts being prevented.

Sources of Error.

The errors which may affect the tests are as follows:

1. Moulding the Mortar. (a) In the tests of the strength of cement mortars it has been found that for a maximum strength, a certain proportion of water is required and that a greater or less amount would weaken it. This is probably true of the permeability of mortar. The author used his judgement as to the amount of water to use, and has recorded the quantity employed.

(b) No machine was used in moulding the mortar, but the mortar was rammed until, in the author's judgement, it could be

rammed no more. The time of ramming occupied from two or three minutes with the mortars, and five minutes with the neat cement.

2. Change of Head. The tub in the top of the building was filled at the beginning of each set of experiments. In no set of experiments did the water lower more than 0.6 ft. Hence the head was 33.3 $\pm$ .3 ft. and the pressure 1.44 $\pm$ 0.13 lbs. per sq. in.

3. Contact of Funnel with Mortar. There may have been a tendency for the water outside of the funnel to seep in, or vice versa, especially so in the weaker mortars where the coarser sand was used; but in the opinion of the author this tendency was very small.

4. Variation in Size of Funnels. The funnels varied in diameter between 2".50 and 2".52 which would produce a variation in the area covered by the funnel of .09 sq. in. and the area would be 4.95 $\pm$ .05 sq. in.

5. Value of Painting. The value of the painting of the cylinders of mortar with shellac is not known. In removing the cylinders at the end of the test, some difficulty was had, since the shellac by adhering to the hose often held the mortar cylinder against the full head of water. When the cylinder was finally removed, patches of shellac were left on the walls of the hose, while that left on the cylinders appeared to be in fair condition.

6. Evaporation. To determine the amount lost by evaporation from the bottles, the author made a "dummy" test, putting

into a bottle 500 grams of water and attaching a funnel to a mortar cylinder the same as in the other tests. In this case however water was not turned into the hose. At the end of ten days, the water in the bottle was weighed showing a loss of less than .5 gram. Hence the loss by evaporation need not be taken into consideration.

Data and Results of Experiments.

With the apparatus described above the author made about 75 experiments on the permeability of mortars. The data and results of these experiments are found in tabular form on the next page.

TABLE II.

Data and Results of Experiments on Permeability of Cement Mortars.

The mortar under a head of 33 ft.

Ref. No.	Kind of Cement	Fineness of Sand	Proportion Cement to Sand	Water used in Mixing Per Cent	Thickness of Mortar, Inches	Age of Mortar when Tested, Days	Length of Time under Test, Hours	Amount of Water passing through Mortar, Grams	Equiv. Amount of Water passing an Area, 1 sq.ft., Cu. ft.
1	G.Port.		Neat	23	2.0	8	240	0.0	0.0
2	"		"		"	"	"	0.0	0.0
3	"		"		"	"	"	0.0	0.0
4	Louisv.		"	29	1.9	"	"	0.0	0.0
5	"		"		"	"	"	0.0	0.0
6	"		"		"	"	"	0.0	0.0
7	Utica		"		1.75	21	104	0.0	0.0
8	G.Port.	20	1:1	13	1.75	10	112	0.0	
9	"	"			1.75			113.0	0.0010
10	"	Qtz			1.90			0.0	
11	"	"			1.90			51.0	0.0004
12	"	20-30			2.0			0.0	
13	"	"			2.0			0.0	
14	"	30			2.0			0.0	
15	"	"			2.0			0.0	
16	"	10			1.9			0.0	
17	Louisv.	20	1:1	19	1.87	8	120	242	0.0020
18	"	"						74	0.0006
19	"	Qtz						73	0.0006
20	"	"						68	0.0006
21	"	20-30						43	0.0004
22	"	"						56	0.0005
23	"	30						32	0.0003
24	"	"						80	0.0008
25	"	10						Broke in machine	
26	Utica	20	1:1	22	1.87	25	104	1.0	.0000
27	"	20-30			1.87			0.0	.0000
28	"	30			1.87			0.0	.0000
29	"	Qtz			1.87			3.0	.0000
30	"	10-20						Crushed in testing	
31	G.Port.	20	1:2	11	2.0	15	200	5.0	.0000
32	"	20-30			2.0			3.0	.0000
33	"	30			2.0			5.0	.0000
34		Qtz			2.0			0.0	.0000

TABLE II Continued.

Ref. No.	Kind of Cement	Fineness of Sand	Proportion Cement to Sand	Water used in Mixing Per Cent	Thickness of Mortar, Inches	Age of Mortar when Tested, Days	Length of Time under Test, Hours	Amount of Water passing through Mortar, Grams	Equiv. Amount of Water passing an Area 1 sq.ft., Cu. ft.
35	Louisv.	20	1:2	15	2	15	200	410	.0021
36	"	20-30			"			252	.0013
37	"	30			"			39	.0002
38	"	Qtz			"			119	.0006
39	"	10-20			"			107	.0005
40	Utica	20	1:2	15	2.12	18	104	25	.0004
41	"	20-30			2.12	18	104	18	.0002
42	"	30			2.25	22	54	19	.0003
43	"	Qtz			2.12	22	54	23	.0004
44	"	10-20			2.12	22	54	3	.0000
45	G.Port.	20	1:3	10	2	26	104	36	.0004
46	"	20-30			"	26	104	102	.0010
47	"	30			"	12	45	245	.0035
48	"	Qtz			"	12	45	12	.0003
49	"	10-20					Crushed in testing		
50	Louisv.	20	1:3					" "	"
51	"	20-30						" "	"
52	"	30						" "	"
53	"	Qtz		13	1.87	12	45	323	.0073
54	"	10-20			1.87	12	45	686	.0156
55	Utica	20	1:3	12	2.0	10	54	50	.0009
56	"	20-30			"	10	54	46	.0009
57	"	30			"	10	54	81	.0015
58	"	Qtz			2.25	10	54	94	.0018
59	"	10-20			2.25	10	54	1567	.0300
60	G.Port.	20	1:4	10	1.87	7	45	673	.0156
61	"	20-30			1.87			51	.0013
62	"	30			1.87			213	.0049
63	"	Qtz			1.87			174	.0040

All specimens from this point either broke in testing, or when introduced into the cylinder permitted the water to filter through it in a stream.

Discussion of Results.

Upon examination of Table II it is found that there are wide variations in the results of experiments in the same series as for example: Nos 9 and 11 in series 8- 16, Nos 17 and 23 in series 17- 25, Nos 35 and 37 in series 35- 39, Nos 47 and 48 in series 45- 49, Nos 56 and 59 in series 55- 59 and Nos 60 and 61 in series 60- 63. The cause of these variations is not known.

In the Louisville mortar No. 50- 53 the test specimen crushed before a tight joint was secured, as was also the case with the Louisville and Utica mortars with one part cement and four parts sand. In all mortars with a greater proportion of cement to sand than one to four, the water was forced through the mortar in a stream.

Conclusions.

From a study of Table II, the following conclusions have resulted. These conclusions, however refer only to water under a head of less than 35 ft.

1. The German Portland, Louisville, and Utica neat cements are impermeable.

2. For a proportion of sand to cement of one to one, the German Portland and Utica mortars are practically impermeable.

3. For a proportion of sand to cement of two to one, the German Portland is practically impermeable.

4. The Louisville mortars are much more permeable than the German Portland or Utica.

5. All mortars containing a proportion of sand to cement greater than four to one and under a head of 35 ft. or more are

of no value in retaining water.

6. The grade or kind of clean sand, of size No. 10 or less, does not effect its impermeability.

7. The relative value of cement mortars for impermeability are German Portland, Utica and Louisville.